NASA-TM-112393

A SUBJECTIVE TECHNIQUE FOR CALIBRATION OF LINES OF SIGHT IN CLOSED VIRTUAL ENVIRONMENT VIEWING SYSTEMS [1]

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7N-61-7M
027452

Abstract: Improving the design of virtual environment systems requires calibration of the displays. We employed a psychophysical technique of subjective judgment of visual direction to provide this calibration. Our data indicated that this technique provided a way to confirm correct graphics field of view selection and to measure actual optical distortion.

INTRODUCTION

It is generally assumed that virtual environment systems will improve the interactions of people with machines by presenting multisensory information to users in ways allowing more natural, presumably more efficient, user-machine interactions (Kalawsky, 1993; Ellis, 1991). The principal technical obstacles to the realization of useful virtual environment systems include appropriate calibration, design of optimal operating characteristics, such as those relating to the dynamics of cursor control, and design of efficient interaction syntax for command and control (e.g. Jacoby and Ellis, 1992).

Improvements in the design of optimal operating characteristics requires the capacity to determine the fidelity of the overall environmental simulation through reference tasks (Ellis, Tyler, Kim, & Stark, 1992; Nemire, Jacoby, and Ellis, 1994) and to determine the physical performance characteristics of the hardware components of the environmental simulator. Some of these characteristics, such as transfer functions of a 6 dof tracker (Adelstein, Johnston, and Ellis, 1992), may be objectively measured.

In some cases however, direct objective measurement of the component performance is difficult. For example, measurement of the line of sight angles (LOS) are necessary to ensure 1) that the proper graphics field of view angle is selected for the viewing optics and 2) that actual optical distortion may be directly measured. However, empirical measurements of the LOS presented in a low-cost, closed head-mounted display as that originally developed at NASA Ames Research Center in 1985 are difficult to accomplish. Though analytic computations may be conducted to determine the LOS patterns presented in closed, head-mounted displays (Robinett and Rolland, 1992), theodolitic verification of these directions is difficult because of positioning requirements. Precise measurements can be made with see-through systems because such systems allow optical superposition of computer generated imagery on physical objects (Hirose, Kijima, Sato, and Ishii, 1990; Ellis and Bucher, 1992). Vernier alignment can then be used to determine registration between physical and virtual reference objects. Such alignment is not possible in a closed viewing system.

Howlett (1991) and Robinett and Rolland (1992) have presented algorithms and techniques to predict the distortion resulting from viewing visual stimuli in a popular head-mounted display. Their reports, however, present analytic predictions of optical distortion produced by the viewing optics in an idealized viewing situation. The question arises whether these analytic predictions accurately describe LOS distortion in actual equipment. Since optical distortions manifest themselves in the pattern of monocularly viewed LOS to visual targets, subjective estimates of LOS directions can be used to measure the distortion. The technique discussed below provides an example of how a psychophysical technique of subjective judgment of visual direction can be adapted to enable a verification of head-referenced LOS in closed virtual environment displays.

Manual pointing with the unseen hand is a convenient technique to determine subjective LOS to a visual target, i.e. the visual direction of the target. The technique of open-loop pointing has been selected because it is convenient and can be performed with reasonable accuracy. However, pointing may be afflicted with subjective errors. We can measure these subjective errors by asking each subject to point to physical targets at known locations. Careful optical substitution of virtual targets, will thereafter provide the subject with virtual targets from which the subjective error may be removed. The following discussion briefly describes how we successfully implemented this scheme in measuring virtual direction in a LEEP optics based virtual environment viewing system similar to Fisher, McGreevy, Humphries, and Robinett (1986) but using

Presented to the Society for Information Display, Seattle, Washington, May 16-21, 1993

a Skywriter graphics system with WorldToolKit for image generation.

EXPERIMENT I

METHODS

In our empirical studies, we asked four subjects to point with their unseen hand to virtual and physical visual targets presented as vertical posts positioned on both physical and virtual horizontal hemicircular planes centered on the subjects' right eye. Target positions were 0 to 35 degrees in 5 degree increments. Subjects were seated with their heads restrained for all conditions. They were asked to accurately point to the targets with their right hand so that a LOS direction with respect to their eye could be mechanically measured. During pointing in the virtual environment, subjects wore a head-mounted display (Figure 1). During pointing in the physical environment, subjects rotated the virtual display out of view so they saw only a comparable physical environment. Subjects used an identical pointing technique in both environments. The presentation order of these two conditions was counter-balanced.

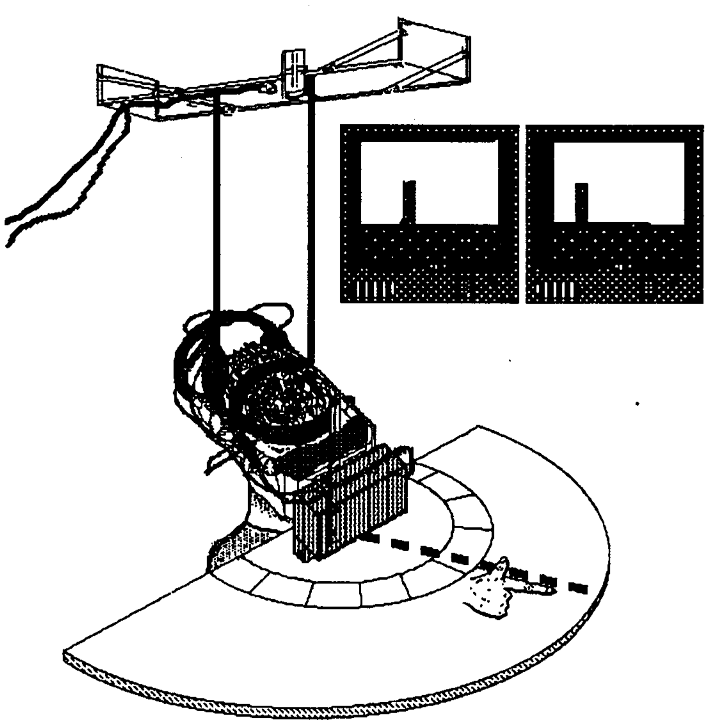

Figure 1. The subject points in the visual direction of a post presented as a monocular, virtual image.

RESULTS

Subjects pointed with remarkable accuracy to the physical targets (Figure 2). Average results reflect the individual data and show that in the physical environment the subjective pointing direction was a very good linear function of the physical direction. The slope was almost the expected 1.00 and the offset was near 0 degrees. When applied to the virtual pointing data, our technique revealed a difference in setting the graphics field of view angle with a scaling factor of about 1.5 and a rotational misalignment of about 6 degrees.

To correct for artifacts in the pointing data resulting from the particular apparatus employed, we subtracted the pointing error in the physical environment from the pointing error in the virtual environment. We then corrected for the calibration error by dividing the resultant value by the slope of the function that described pointing to virtual targets.

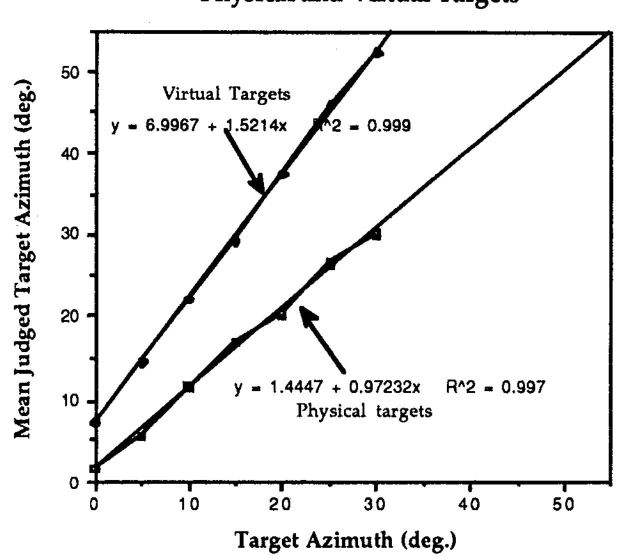

Figure 2. Regression through the responses averaged across four subjects shows the relationship between target azimuth and judged target azimuth for both real and virtual targets. The difference in the slopes of the regression lines indicates an incorrect value for the field of view angle was used for the graphics of the virtual display.

Figure 3 shows that our technique of correction can account for practically all of the differences between judged azimuths in the virtual and physical pointing situations. The collected data for both the virtual and physical pointing exhibits a striking linearity given the radially symmetric distortion that is expected in the optic display (Howlett, 1990; Robinett and Rolland, 1992).

EXPERIMENT II

We believed the difference in scaling factor of 1.5 observed in the first experiment was a result of our inappropriately chosen graphics view angle. We also thought the rotational misalignment of 6 degrees observed in the first experiment was a result of a misalignment between the subjective coordinates of the observer and the coordinates of the physical and virtual environments. Consequently, in our second experiment, we tested these hypotheses. We used the same methodology as in the first experiment except for the following changes: 1) we used a new view angle, based upon different calculations for the field-of-view of our head-mounted display, 2) we aligned the physical and virtual environments with the observer's perceived straight ahead (straight ahead of their right eye) and 3) we employed target positions of 0+/- 15, 30, 40, and 45 degrees.

RESULTS

Figure 4 shows that our attempts to align the physical and virtual environments with the observer's perceived straight-ahead did not substantially change the rotational error; errors in both experiments were similar. There must be some other source for this baseline shift. Further experimentation is in progress to determine if the optical center of the lens system correctly corresponds to the center of the view-port in the LCD display.

Figure 4 also shows that our choice of view angle did decrease the magnitude of the scaling factor. In Experiment I, the slopes of the pointing functions were 1.5 and 0.97 in the virtual and physical environments, respectively. In contrast, in Experiment II, the slopes of the pointing functions were 0.9 and 0.9 in the virtual and physical environments, respectively. Pointing in both environments can be described by similar linear functions when the correct graphics field of view angle is used.

In Figure 4, we plotted the predicted distortion of the LEEP optics based on Robinett and Rolland's (1992) computational model because we wanted to determine the relationship between the predicted distortion and pointing errors. The comparison indicates that in the central 80 degrees of the virtual visual field, the optical distortion in the display was not sufficient to cause a deviation in the pointing behavior. The similarity of functions indicates that the algorithm adequately predicts the pointing errors in the central 80 deg field of the virtual environment.

DISCUSSION

We have developed a subjective pointing technique that allows measurement of LOS directions in closed virtual environment display systems. This technique provides a way to confirm correct graphics field of view selection and a method to measure actual optical distortion

Implications of these findings are that designers of virtual visual displays may not have to be concerned with the contribution of optical distortion to open-looped visual motor coordination in the central 80 degrees of the visual virtual environment. Further experimentation is necessary to determine whether our results can be generalized to other indices of spatial orientation and to investigate whether optical distortion in the field periphery adversely impacts spatial perception and orientation in visual virtual environments.

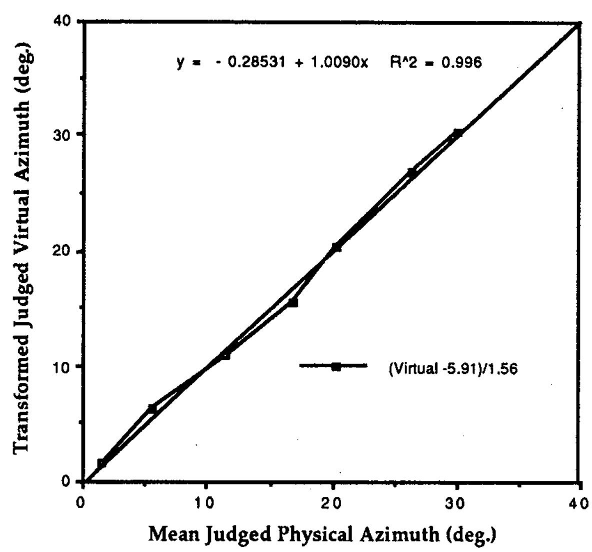

Figure 3. Application of a linear correction based on differences between the judgments of visual directions to physical and virtual targets.

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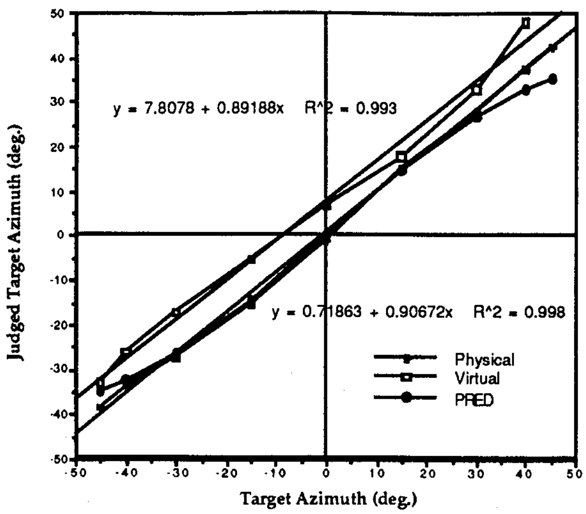

Figure 4. Average results from 3 subsequent subjects who repeated the experiment after we corrected the graphics field of view angle. Notice that the slopes of the regression through the judgment data for the physical (lower) and virtual (upper) are almost equal. Also note that in the +-40 deg range, there is not much distortion and that the predictions of distortion (PRED) from Robinett and Rolland's (1992) model are similar to the observed behavior in the physical and virtual environments.

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